Alberta

Some Studies of Hydrogen Technologies Suitable for Alberta

Project supported in part by the Alberta Oil Sands Energy Resources Research Fund

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Foreword

Beginning in 1976, numerous projects were initiated in Alberta by industry and academic research institutions to help make better use of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rested with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities focused primarily on coal, energy conservation and renewable energy, and conventional energy resources. In 1988/89, a hydrogen research component was added.

Administration for the A/CERRF program was provided by staff within the Research and Technology Branch of Alberta Energy.

The A/CERRF program ended on March 31, 1991 and the support it provided has been replaced by funding from the Alberta government.

A series of technology transfer booklets begun in 1986 with A/CERRF support continues to make research results available to industry and others who can use the information.

This service will continue until all A/CERRF projects have been described.

For more information about other publications in the series, please refer to page 15.

Some Studies of Hydrogen Technologies Suitable for Alberta

Introduction

Both the development of Alberta's heavy hydrocarbon resources, and Canada's security of supply of conventional transportation fuels, are dependent on the availability of low-cost hydrogen.

Already, Alberta produces and consumes more than half the hydrogen in Canada, and this can be expected to increase in the future. The cost to produce hydrogen, however, represents a significant portion of the overall costs of the processes in which it is used.

Thus, in 1987, a project supported by A/CERRF was initiated to identify current producers and consumers of hydrogen in Alberta. Also, technology developments that are required to improve hydrogen production, storage, transportation and use were identified. The conclusions reached in this inventory study were released in April 1988, and a joint industry/government steering committee was created in August 1988 to formulate and oversee a hydrogen technology research and development program for Alberta. The outcome was a cost-shared research program that was initiated in December 1988.

Currently, the Hydrogen Technology Research Program comprises the following components, each of which is considered to represent an aspect of hydrogen technology that requires commercial-scale development within 10 years.

The components are:

- advanced or alternative hydrogen production technologies;
- production technologies that work synergistically with those being developed in a separate coal research program;
- hydrogen separation technologies;
- large volume hydrogen storage;
- transportation/distribution of hydrogen;
- optimum end-uses of hydrogen; and
- materials and safety technology.

Thus far, 18 research projects have been initiated. The results of the inventory study that preceded the program, as well as some of the projects completed subsequently, are reported here.

Hydrogen Technology Inventory

An inventory of hydrogen production and use in Alberta was carried out by RTM Engineering Ltd. in 1987/88. In addition to defining the extent to which hydrogen is produced and used in Alberta's petroleum and petrochemical industry, the study also found a growing use in applications such as food processing, steel production, metallurgy and pharmaceutical manufacturing.

It was found that Alberta industries produce 55 per cent and consume 63 per cent of all hydrogen generated in Canada. Furthermore, large quantities are produced in excess of requirements by individual producers, making substantial amounts available for transfer to consumers in the event that appropriate storage and transportation facilities are established.

Hydrogen Production in Alberta (tonnes/day)

Process	Production
Chemical	
Ammonia	1 295
Methanol	951
Ethylene	244
Other	76
Oil Sands/Refining	
Steam Methane Reforming	767
Catalytic Reforming	117
Other	38
Miscellaneous	1
Total	3 489

(Source: Alberta Hydrogen Technology Inventory, RTM Engineering Ltd., 1988.)

Approximately 62 million cubic metres of hydrogen are produced in Alberta every day, having an annual value of $500 to $600 million. While the greatest production and consumption is by ammonia and methanol producers, it is generally agreed that the greatest increase in production and use in the future will involve Alberta's hydrocarbon resources.

In the near term, this growth will be associated with bitumen and heavy oil upgrading. This could be accompanied by coal gasification processes that allow hydrogen recovery as an option. Later, it is possible that co-processing of coal and bitumen will become an economically feasible method for producing transportation fuels. This will require substantial quantities of hydrogen.

It was found that hydrogen research capability and experience exists in several Alberta companies and universities, and this proficiency was judged to be appropriate for conducting the research needed to achieve desired improvements in hydrogen production and use.

Hydrogen Consumption in Alberta (tonnes/year)

Process	Consumption	%
Chemical		
Ammonia	523 000	41.1
Methanol	220 900	17.4
Oil Sands	201 600	15.8
Refining	75 700	5.9
Other Chemicals	7 600	0.6
Miscellaneous	1 400	0.1
Fuel		
Ammonia	9 400	0.7
Methanol	126 200	9.9
Oil Sands	24 600	1.9
Refining	28 900	2.3
Other Chemicals	37 400	3.0
Miscellaneous	200	-
Venting, Incineration	16 100	1.3
Total	1 273 000	100.0

(Source: Alberta Hydrogen Technology Inventory, RTM Engineering Ltd., 1988.)

Thus, during the second half of 1988, the RTM inventory report was used as a catalyst to initiate discussions with industrial and academic researchers regarding the direction that a hydrogen research program should take.

Beginning with recommendations made in the RTM study, and superimposing the results of several discussion sessions involving industrial and academic researchers, guidelines were established for the development of a research program suited to Alberta's requirements. The components of this program are outlined below.

Hydrogen Production

Water (H_2O), methane (CH_4) and hydrogen sulphide (H_2S) are considered to be the three primary sources for hydrogen production in the immediate future in Alberta. These three feedstocks represent the richest, cheapest and most readily available hydrogen-containing sources. Currently in western Canada, steam-methane reforming is the most important and best developed hydrogen production method, with the Modified Claus process for converting hydrogen sulphide to sulphur representing a potentially significant alternative. In particular, any process capable of economically splitting H_2S should produce only hydrogen and elemental sulphur, without the carbon dioxide by-product that results from steam-methane reforming.

In evaluating alternative hydrogen production technologies, they must be judged to be new or improved relative to steam-methane reforming. This requires evaluation of several factors, including process chemistry, energy input, process engineering, product separation and purification, and by-product uses.

Hydrogen Separation

Separation of produced hydrogen from unreacted feedstock or reaction by-products is one aspect of the Hydrogen Technology Research Program that deserves special attention. Successful integration of separation techniques with particular production processes or combinations of processes is regarded as a high priority. Associated with separation research is the need to minimize undesirable by-products, or recover those having high market value as chemical building blocks or specialty products.

Materials and Safety Technology

Each of the previous research areas will require some complementary research that focuses on the metallurgy of materials. Also, the physical and thermodynamic properties of pure hydrogen and hydrogen mixed with other gases must be determined. This information is applicable to the safety and control of hydrogen-related operations, as well as the transportation and storage of hydrogen/natural gas mixtures.

Partial Oxidation of Methane for the Production of Hydrogen and/or Synthesis Gas

Currently, the hydrogen used in Alberta is made by steam-methane reforming, a process that takes advantage of Alberta's abundant supplies of natural gas. The reaction proceeds in two steps, as follows:

(1) $CH_4 + H_2O \rightleftharpoons CO + 3H_2$

(2) $CO + H_2O \rightleftharpoons CO_2 + H_2$

This process has several drawbacks, however. For example, it requires the supply of external thermal energy to the reactor, and it uses expensive and difficult-to-maintain equipment.

Another method that might be used to generate hydrogen from natural gas involves partial oxidation of natural gas. Although this process uses relatively expensive oxygen, the equipment needed tends to be less expensive and requires little maintenance. Also, the process is more flexible in its ability to handle a variety of feed materials.

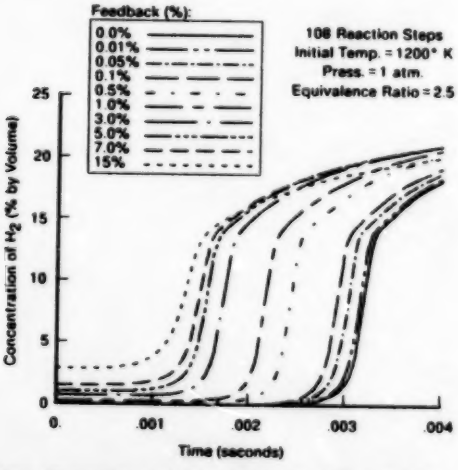
Thus, an investigation of the partial-oxidation approach was undertaken at The University of Calgary, with an emphasis on examining the kinetics of the reaction.

It was found that the partial oxidation of methane can involve 108 steps and 28 individual chemical species, making it a complex reaction to model. Nonetheless, the generation of hydrogen and other products with time was simulated by computer, and the effects of process changes could be measured. One of the important findings of this investigation was that recirculation of some of the reaction products could promote faster conversion of methane to hydrogen. This characteristic could lead to a method for producing hydrogen economically.

The kinetic analysis also showed that partial oxidation is better suited for the production of molecules having a higher molecular weight than hydrogen, but not for hydrogen itself. While this may have some important implications for the petrochemical industry, none of the companies participating in the Hydrogen Technology Research Program was willing to provide the level of funding needed to continue this project. Thus, the project was terminated after one year.

The project final report provides a useful summary of the state-of-the-art of partial oxidation processes for methane.

Effect of Exhaust Gas Recirculation on Production of Hydrogen



(Source: Examination of the Partial Oxidation of Methane for the Production of Hydrogen and for Synthesis Gas, Karin, G.A., University of Calgary, 1990.)

Conversion of Hydrogen Sulphide to Hydrogen and Organosulphur Compounds by Metal Catalysts

In 1989, a project was initiated by Alberta Sulphur Research Ltd. of Calgary to investigate methods for using hydrogen sulphide to produce hydrogen and commercially valuable chemicals derived from sulphur. Specifically, the objectives were:

- to confirm literature observations that metal complexes can split H_2S into hydrogen and metal-combined sulphur at ambient conditions;
- to determine the feasibility of converting the metal-combined sulphur to industrially important organosulphur chemicals; and
- to examine the feasibility of recycling the metal complexes for use in further dissociation reactions.

Based on information in the scientific literature, complex compounds containing either nickel, ruthenium or palladium were prepared. When reacted with hydrogen sulphide, all produced hydrogen. In particular, the reactions with nickel and ruthenium complexes generated significant quantities of hydrogen. Reactions with nickel complexes proceeded rapidly, but the resulting nickel-containing by-product decomposed. The reactions involving ruthenium compounds proceeded at more moderate rates, but the by-product could not be converted into useful organosulphur compounds.

A similar pattern of reaction was observed using palladium complexes, but attempts to recover useable sulphur from the resulting by-product were not successful.

It was concluded that although this approach is clearly capable of releasing hydrogen from H_2S, more research needs to be done on the overall mechanism before it can be considered as the basis for an industrial process.

A second project to produce hydrogen and sulphur from H_2S is currently under way at Alberta Sulphur Research Ltd. The objective is to employ the high temperatures used in Modified Claus plants for direct thermal decomposition of H_2S to hydrogen and sulphur. Thus far, laboratory procedures have been developed to obtain significant yields of hydrogen at temperatures that are consistent with normal Claus plant operations. This project is continuing. When completed, it will be described in a later publication.

The Carbon Monoxide Catalysed Conversion of Hydrogen Sulphide to Hydrogen and Sulphur[1]

Although electrolysis and thermal conversion are often studied as potential methods for commercial-scale conversion of hydrogen sulphide to hydrogen, an alternative route was explored at the University of Alberta. The objective was to produce hydrogen (and carbonyl sulphide) from a two-step reaction between hydrogen sulphide and carbon monoxide, and then regenerate carbon monoxide for re-use. Those two steps are:

(1) $H_2S + CO \rightsquigarrow H_2 + COS$

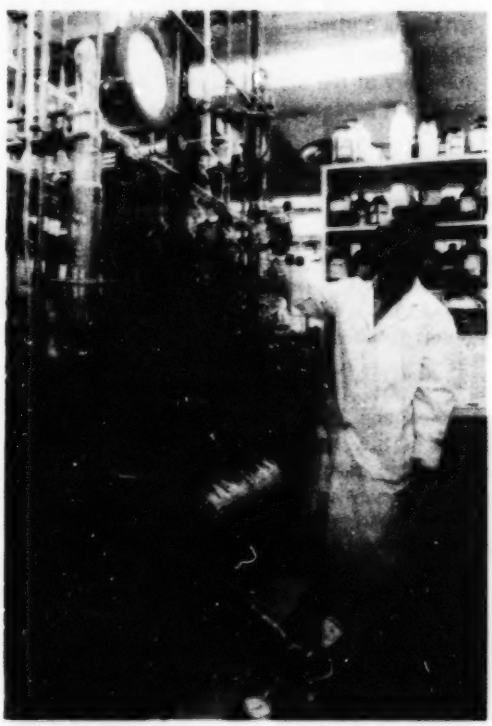
(2) $COS \rightsquigarrow CO + S$

An analysis of the kinetics of these reactions indicated that the overall reaction should be more economically attractive than the Modified Claus Process. Following a review of the technical literature on the chemistry and kinetics of related reactions, a series of experiments was designed to test the proposed two-step process. Initially, a few experiments were carried out to duplicate some that were reported in the literature, which did not employ a catalyst. While proving that hydrogen and carbonyl sulphide can be produced by reacting carbon monoxide with hydrogen sulphide, the conversion rates were found to be negligible - only two per cent over 24 hours.

Conversely, when a NiS/alumina catalyst, one atmosphere pressure and a reaction temperature of 253°C were used, conversions to hydrogen and carbonyl sulphide, representing up to 94 per cent of the thermodynamic equilibrium value, were achieved. Several experiments were carried out to determine the influence of reaction temperature, residence time and ratios of reactants on the conversion rate.

One of the attractive features of this process is the use of a readily available, stable and inexpensive catalyst.

Some initial work was completed with the second reaction step. While the results were promising, there was insufficient time within the limits of this project to pursue it further. At the conclusion of the project, discussions were underway to initiate a new project and continue studying this reaction step.



Laboratory arrangement used to study the carbon monoxide catalysed conversion of hydrogen sulphide.

(Photo courtesy of Dr. O.P. Strausz)

[1]Funding was provided by Gulf Canada Resources Limited and A/CERRF.

Cold Plasma Decomposition of Hydrogen Sulphide

Although the scientific literature now contains a substantial body of research on attempts to produce hydrogen and sulphur from hydrogen sulphide, there has been little success in developing a commercial process.

For various reasons, the traditional approaches have encountered problems that remain unsolved. For example, electrolysis of H_2S in alkaline solutions is accompanied by sulphur deposition on the anode. Direct thermal conversion of H_2S requires high temperatures and must provide some means for preventing the recombination of the reaction products. Other approaches have been hampered by slow reaction rates and high energy requirements.

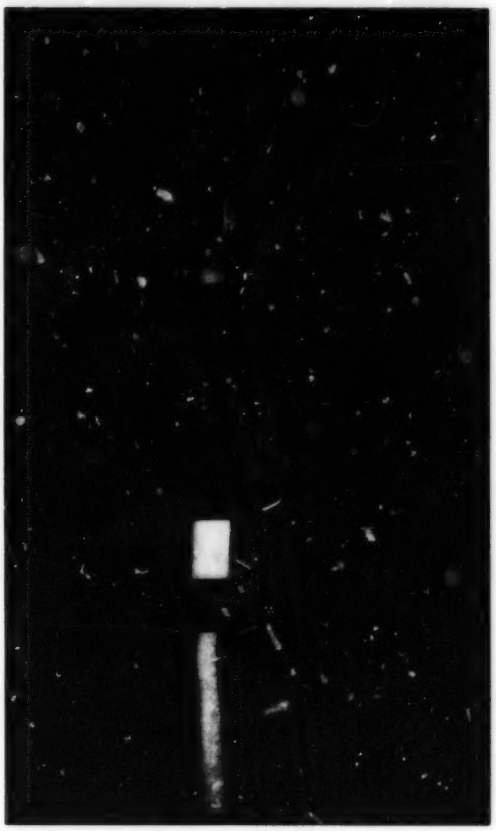
One process that might overcome some of these difficulties involves the use of microwave energy to create a "cold plasma" of H_2S. In the plasma state, hydrogen sulphide is almost completely ionized, and collisions between electrons and molecules can decompose it into its elemental components (hydrogen and sulphur) with less recombination than occurs in electrolysis-induced reactions.

In studies reported in the scientific literature, successful decomposition of hydrogen sulphide has been proven, but at conditions that would not be practical for large-scale, commercial operations.

Thus, a project was carried out by Atomic Energy of Canada Limited (AECL), in collaboration with Shell Canada Limited, to investigate the microwave-induced decomposition of hydrogen sulphide at pressures that are more suitable for commercial use.

One of the objectives of this sort of work is to prevent the plasma from becoming extinguished at pressures that are less than those desired, while encouraging sulphur to condense from the plasma to drive the reaction toward completion.

A special apparatus was designed and constructed for this project. It included a system for efficient removal of sulphur formed during the decomposition reaction, and a method for recirculating any unreacted hydrogen sulphide.



A typical cold plasma as produced in the experiments at AECL Research.

(Photo courtesy of AECL Research)

Hydrogen sulphide was converted to hydrogen and sulphur at various flow rates. Experiments were divided into groups according to the gas flow rate and "forward power" (a component of the microwave energy) to determine the energy efficiency, plasma extinction pressure and temperature at the exit of the plasma reactor.

At low gas flow rates, the decomposition yield was as high as 60 per cent. Also, the effects of feed gas contaminants, methane and carbon dioxide on percentage decomposition, product formation and the electric field at the plasma were measured. The percentage decomposition of H_2S was maintained in the presence of carbon dioxide and increased in the presence of methane.

Although this work could be supported by A/CERRF for only one year, the investigation will continue with alternative funding under the Alberta Hydrogen Research Program.

Hydrogen Separation and Purification[1]

Hydrogen separation and purification are critical to processes that produce or use hydrogen. Effective separation technologies are required not only for hydrogen feedstock purification, but also for the recovery of hydrogen from plant offgases.

The removal of impurities from hydrogen usually requires a combination of several separation techniques to capitalize, for example, on the high recovery rates of one technology and the capability of another to produce high-purity products. This makes the process cumbersome and inefficient, however. Consequently, in a project carried out at the Alberta Research Council, a hollow fibre permeation system was integrated with a separation process known as pressure swing adsorption (PSA).

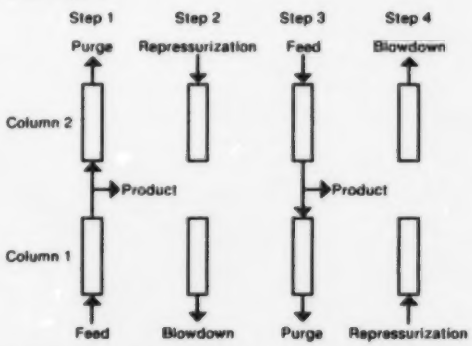
In PSA, as in all adsorption systems, separation is achieved when substances are adsorbed, or become concentrated, on the surface of materials called adsorbents.

For such systems to be viable on a commercial scale, a regeneration stage is necessary to allow the adsorbed substances to be removed and the adsorbent to be regenerated. In PSA, regeneration is accomplished by reducing the pressure on the bed of adsorbent and adsorbed substances, and then purging the bed with a portion of the product gas. The cycle time from adsorbing to regenerating can be only a matter of seconds, making it possible to pass large volumes of gas through the system. In its simplest form, PSA comprises two adsorbent beds operated in sequence in four cyclic steps.

While PSA separation is used widely to purify hydrogen on a commercial scale - largely because it produces a high-purity product - the product recovery rates are relatively low, ranging from 70 to 85 per cent. On the other hand, some membrane separation techniques favour high recovery rates. In this project, it was believed that integration of techniques having these attributes could lead to smaller and more efficient separation devices.

Thus, a hollow-fibre separation system was constructed, and an automated PSA system was built to test the hollow-fibre device for hydrogen separation and purification. Minute solid particles of adsorbent were packed into specific areas of the hollow fibre modules. In subsequent experiments, different types of fibres and adsorbents were tried.

Basic Process Scheme of Pressure Swing Adsorption



(Source: Final Technical Report on Hydrogen Separation and Purification, Pan, C.Y., E. Hadfield and C. McMinis, Alberta Research Council, 1991.)

In a typical experiment, mixtures of hydrogen and carbon dioxide were separated in the hollow fibre adsorber, using activated carbon as the adsorbent. Cycle times as short as 10 seconds were used. Hydrogen recovery rates of 76 per cent were achieved, regardless of the cycle time.

[1]Funded jointly by Alberta Research Council and A/CERRF.

Extensive tests employing a bench-scale pressure swing adsorption device, along with zeolite crystals and activated carbon powder, showed that even a small module can process large volumes of feed gas.

While the process produced ultra high purity hydrogen, recovery rates were lower than desired. This resulted from the necessary cyclic pressurization and depressurization steps. A novel pressure swing membrane permeator has been designed to accommodate these changes in pressure.

A detailed investigation of the sorption and permeation components of the system was performed, using various gas mixtures and adsorbents. The test program showed that hydrogen can be separated effectively. The most important advantage of the system is its ability to accomplish this level of hydrogen separation at high rates of feed gas passage through the unit.

A mathematical model of the hollow fibre pressure swing adsorption process was developed. It was used to help analyse and optimize the process.

Hydrogen Producer/Consumer Networking

In 1989/90, a study was undertaken at the Alberta Research Council to develop a model of possible hydrogen transfers among producers and consumers. The objective was to demonstrate how more economic use could be made of hydrogen than at present, and show how the need to flare hydrogen could be minimized by a system for delivering excess hydrogen production to potential customers. Also, by quantifying the current hydrogen situation in Alberta, it might be possible to attract new industry to the province.

A data base of current producers and consumers was established with information provided by RTM Engineering Ltd. Using this information, a computer program capable of determining the minimum cost distribution of hydrogen in Alberta was created. The model assumes all transfers will occur by means of a pipeline. Essentially, the optimal distribution of hydrogen through a pipeline network was modelled as a minimum cost-capacitated trans-shipment problem. In this concept, each company has a number of units which are classified as demand, production, flare or fuel.

Thus, hydrogen flows from source units to the parent company, and from there to demand units. There are no flows between units; they can be connected only through a parent company. Also, the cost associated with unit/company transactions depends only on the market value of hydrogen at the source.

Included in the data base and numerical solutions were several factors and assumptions that affect cost. They include hydrogen purity at source; hydrogen purity in the pipeline (assumed to be 99 per cent); pipeline pressure (assumed to be 7 MPa); purification and compression costs (assumed to be $200/tonne); a value of $665/tonne for hydrogen fuel, versus $400/tonne as a source from flare; and hydrogen production by steam-methane reforming.

To demonstrate the model, two examples were considered. The first used a hypothetical company located at Lloydminster having an annual demand of 100 000 tonnes of hydrogen. Using the information in the data base, a hypothetical minimum-cost pipeline network was assembled to meet this demand. The annual cost was calculated to be $76 million: $62.7 million to purchase the hydrogen and $13.3 million to transport it.

In a second example, an additional company at the same location and having the same demand was assumed. For this arrangement, an annual cost of $182 million was calculated.

The final simulation model is available for use on IBM-compatible personal computers, and a user's manual was prepared. Alberta Research Council should be contacted directly for access to the software.

Example 1: Upgrader 1 at Lloydminster

Demand

Company	Location	Tonnes/Yr
Upgrader 1	Lloydminster	100 000

Supply

Company	Location	Tonnes/Yr	$Million
Celanese	Edmonton	63 200	42.03
Dow	Ft. Saskatchewan	12 430	4.97
Esso Pet	Edmonton	2 240	1.49
Petro Can	Edmonton	2 080	1.38
Shell	Scotford	16 672	11.08
Sherritt	Ft. Saskatchewan	3 378	1.71

Pipelines

From	To	Tonnes/Yr	$Million
Shell	Dow	16 672	0.44
Sherritt	Dow	3 378	0.20
Dow	Celanese	32 480	0.92
Esso Pet	Celanese	2 240	0.20
Petro Can	Celanese	2 080	0.20
Celanese	Upgrader 1	100 000	11.38

Total Annual Cost = $76.03 Million

Example 2: Upgrader 1 and Upgrader 2 at Lloydminster

Demand

Company	Location	Tonnes/Yr
Upgrader 1	Lloydminster	100 000
Upgrader 2	Lloydminster	100 000

Supply

Company	Location	Tonnes/Yr	$Million
A.G.E. Ltd	Joffre	34 440	22.90
Cancarb	Medicine Hat	1 470	0.60
Celanese	Edmonton	63 200	42.03
Cominco	Joffre	1 000	0.62
Dow	Ft. Saskatchewan	12 430	4.97
Esso Chem	Redwater	1 500	1.00
Esso Pet	Edmonton	2 240	1.49
Glacier	Pincher Creek	2 920	1.96
Nova Cor	Medicine Hat	46 702	31.05
Petro Can	Edmonton	2 080	1.38
Shell	Scotford	21 200	14.10
Sherritt	Ft. Saskatchewan	3 378	1.71
Turbo	Balzac	7 440	4.95

Pipelines

From	To	Tonnes/Yr	$Million
Esso Chem	Shell	1 500	0.41
Shell	Dow	22 700	0.47
Sherritt	Dow	3 378	0.20
Dow	Celanese	38 508	0.97
Esso Pet	Celanese	2 240	0.20
Petro Can	Celanese	2 080	0.20
Cancarb	Nova Cor	1 470	0.20
Nova Cor	Glacier	48 172	9.58
Glacier	Turbo	51 092	8.75
Turbo	Cominco	58 532	5.77
Cominco	Celanese	59 532	6.03
A.G.E Ltd	Celanese	34 440	5.24
Celanese	Upgrader 2	200 000	14.82
Upgrader 2	Upgrader 1	100 000	0.24

Total Annual Cost = $181.82 Million

(Source: Hydrogen Producer / Consumer Networking Transportation and Storage Optimization, Kovacik, G., B. Ozum and M. Oguztoreli, Alberta Research Council, 1990.)

Salt Cavern Storage of Hydrogen

It is generally conceded that current hydrogen production methods are very reliable, and tend to experience little downtime. Nonetheless, in any hydrogen transfer system involving off-site sales of hydrogen to users, the volume of hydrogen demanded will not always coincide with the volume produced. Thus, any proposed hydrogen transfer system must include a storage component to provide some surge for those periods when production and demand do not match.

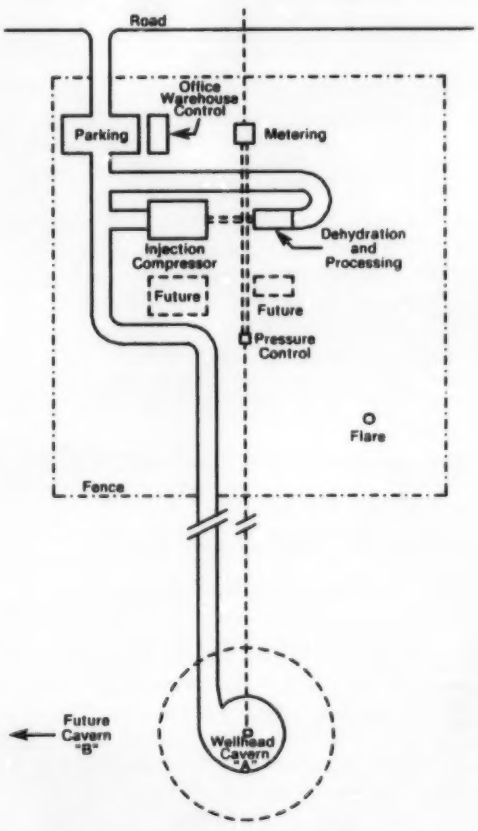
In 1989/90, RTM Engineering Ltd. investigated the concept of using salt caverns in Alberta for hydrogen storage. It was found that several companies use salt caverns to store a variety of hydrocarbons, although none was storing hydrogen. In particular, the Fort Saskatchewan area seems to be well-suited for this purpose.

Generally, it is believed that hydrogen storage technology will be an extension of that used for other hydrocarbons. For instance, salt caverns are already being used for hydrogen storage in northeastern England.

RTM concluded that design and operation of a salt cavern system for hydrogen storage should not be a difficult task, and that most of the information needed to design such a system should be available from sour gas and natural gas experiences. A preliminary design for a salt cavern storage system in the Fort Saskatchewan/Redwater/Scotford area was prepared, and the capital and operating costs for this proposed facility were estimated. The design details, however, are confidential. Persons requiring additional information should contact RTM Engineering Ltd. in Calgary.

It was recommended that several aspects of the system be tested and developed further before commencing with a full-scale operation. They include long-term testing of certain components and/or materials that will come into contact with hydrogen at high pressure, and studies to confirm that no leakage of hydrogen will occur through salt and other reservoir materials.

Hydrogen Storage Conceptual Plot Plan



(Source: Salt Cavern Storage of Hydrogen, RTM Engineering Ltd., 1990.)

Salt Cavern Storage in Alberta

Operator	Location	Natural Gas	Caverns						Total Cap. 10^3M^3
			Ethylene	Ethane	Propane	Butane	Mix	Other	
Amoco	Ft. Sask						4		262
Chevron	Ft. Sask				6	3	1		1026
Cochin	Ft. Sask			3	2				455
Dow	Ft. Sask		3						220
Esso	Ft. Sask				1	1			595
Home	Hardisty				1	3			514
NUL	Ft. Sask		4						510
Procor	Ft. Sask			3	4	2			729
AUSL	Hughenden				2	2			318*
Suncor	Ft. McMurray								Undeveloped

* Abandoned

(Source: Salt Cavern Storage of Hydrogen, RTM Engineering Ltd., April 1990)

Optimum Hydrogen Use in Upgrading and Refining

One of the original premises of Alberta's Hydrogen Technology Research Program was that Canada will need more crude oil from non-conventional sources, such as the oil sands, as reserves of conventional light and medium crude oils decline. In turn, this will create a greater demand for hydrogen, which is used to upgrade synthetic crude oils to refinery-acceptable feedstocks. To keep the costs of upgrading as low as possible, it is necessary that the current methods of using hydrogen be made more cost efficient, or that new or improved ways of using hydrogen be found.

Thus, in a project co-ordinated by the Oil Sands Task Force of the Alberta Chamber of Resources, and carried out by RTM Engineering Ltd., the objective was to review and then select new or emerging technologies that have demonstrated some promise for improving the use of hydrogen in upgraders and refineries. Also, the project updated the hydrogen inventory study completed in 1988.

It was assumed that 15 800 m^3/day of Cold Lake bitumen would be processed in a new upgrader located near Fort Saskatchewan/ Redwater, with startup in the year 2000. This upgrader was treated as either a stand-alone unit or one in conjunction with a refinery that produced motor gasoline, jet fuels and diesel fuel. The actual refinery products were those projected to be in demand in 2000. It was also assumed that both configurations of the upgrader would be expected to meet certain projected environmental standards. This would have a bearing on the types of pollution control systems used by either configuration. Also, environmental standards that are more stringent than those applicable today would influence the characteristics of petroleum products and their relative position in the marketplace.

It was projected that many changes would occur in both the quality of, and demand for, refined products. Higher hydrogen content and lower sulphur and aromatic content were likely. Gasoline consumption would decline, while use of jet fuel and diesel fuel would rise, causing difficulties for current refineries to meet the projected demand. Changes in quality requirements would compound this problem and force significant investment at most existing refineries.

These changes in both the demand for and composition of petroleum products is expected to lead to a hydrogen shortage at current refineries unless on-site steam-methane reforming of natural gas is practised.

Consequently, a combination upgrader/refinery was considered to be the more promising option. It would:

- eliminate duplication of hydrogen processing units for naphtha, jet fuel, diesel fuel and gas oil;
- provide common hydrogen production and recovery facilities;
- avoid the necessity for crude distillation occurring at a separate refinery;
- allow residual products from refining to be converted in the upgrader; and
- provide other synergistic benefits for upgrading and refining.

Furthermore, it was recommended that the upgrader/refinery could be integrated with natural gas conversion. This could permit the production of hydrogen for on-site requirements, the manufacture of chemicals such as methanol, and/or the production of premium refined products. Pitch gasification could also be included in such a scheme.

Further Reading

AECL Research/Shell Canada Limited. 1991. Cold Plasma Decomposition of Hydrogen Sulphide.

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Information regarding the conversion of H_2S to hydrogen and organosulphur compounds is available from:

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For non-confidential information about the cold plasma decomposition of hydrogen sulphide, contact:

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For details regarding integrated permeation/adsorption separation of hydrogen, contact:

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More information about the hydrogen producer/consumer network and access to the software developed for this project are available from:

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Non-confidential details regarding optimum hydrogen use in upgrading and refining are available from:

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Additional copies of this publication and of one other publication on hydrogen research, called *An Introduction to Hydrogen Research in Alberta,* are available from:

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